APPENDIX E

QUALITY ASSURANCE INFORMATION AND SAMPLING PLAN

- Quality Assurance Plan
- Sampling Plan

APPENDIX E

QUALITY ASSURANCE INFORMATION AND SAMPLING PLAN

QUALITY ASSURANCE PLAN

In any study in which samples are taken to represent a larger population, the extent to which the samples accurately represent the population is an issue. It is always possible to draw a sample that is a fluke—that doesn't represent the population well. The best way to ensure representation is to take a number of samples. If the sample size is large, it is more likely that the sample accurately reflects the population from which it is drawn. In general, sample sizes of between 20 and 30 are usually considered large.[1]

In sampling rainfall runoff, other concerns are also relevant. The pollutants that are carried in the runoff can vary, both during the storm, and between different storms. For instance, pollutants can be more concentrated in the early part of the storm, or perhaps are only present if very heavy rainfall mobilized them. There can be contamination by outside sources, such as from the containers used to convey the sample. And there are also considerations about the accuracy to which the analytical laboratory can quantify the concentration of a particular pollutant.

All of the above concerns are factors to consider in designing the quality assurance aspects of a project. They will be discussed in turn as they applied to the Biofiltration Project.

Representation of Sample

Flow-proportioned samples were chosen for this study, rather than grab samples or samples at evenly spaced time intervals, because they are considered more representative of the actual stormwater runoff (since a rainstorm extends over time, and a grab sample taken at only one point in time is not likely to represent the "true" pollutant concentration). Several samples evenly spaced over time would seem to represent the average pollutant load. And if flows are

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1 Another convenient feature of large samples is that the means of the samples tend toward a normal distribution regardless of the underlying population distribution (Central Limit Theorem, Wonnacott & Wonnacott, 1984). This allows the application of parametric statistical methods to the data set.

relatively constant, a time-proportioned sample, as it is called, may indeed be a good estimate of the "true" pollutant load carried.

But rainfall runoff is not constant. A typical hydrograph has one or more peaks, with periods of increasing and decreasing flows. Assuming the contribution of pollutants is fairly constant, samples taken at regular time intervals would ignore the effect of the greater or lesser flow volume in diluting or concentrating pollutants. It would also be difficult to compare results from different rainfall events.

The problem of unequal flow can be dealt with simply by monitoring flow. Knowing the flow at any time allows an automatic sampler to be programmed to collect a sample after a given increment of flow has passed. The harder it rains, the more samples that are collected. The problems with dilution of pollutant concentrations during high flow and concentration during low flows are avoided. Thus flow-proportioned stormwater samples, though not perfect, are more likely to be representative than time-proportioned samples.

Representation of Storms

In addition to concerns about whether the storm runoff is sampled in a representative manner, another concern is about the selection of the storms themselves. One way to ensure representatives in selecting samples is to employ random sampling. Random sampling means that the particular sample taken is as likely to be drawn as any other. Biases that may be affecting the population are therefore minimized. Random sampling results in independent observations, an outcome important for applying statistical analysis.

Random sampling may also be stratified, that is, only a certain subset of the population may be sampled. In the case of the Biofiltration Project, only storms of a certain size and with a 48-hour antecedent dry period were sampled. Thus the storm samples were stratified, being a specific subset of all possible storms.

However, strict random sampling is difficult to apply to storm monitoring. Rainfall events themselves could be viewed as randomly occurring. There is usually poor information about the likelihood, duration, and intensity of rainfall events before they occur. Due to the difficulty of identifying and then randomly selecting a stratified sample, the project sought to collect each rainfall event that met the antecedent dry period criteria, and that promised even odds of producing the required minimum rainfall volumes. This method was not strictly random, but an additional random element was added when equipment malfunctioned, and successful samples were not achieved.

A bigger concern was, however, that the 200- and 100-foot configurations were sampled sequentially. Although this was required due to physical set up constraints, this meant that the potential affects of seasonal rainfall patterns could not be minimized by randomization. For a time, spring storms tended to be of lower intensity than fall storms, making this bias a potential problem. Luckily, later spring storms were of higher intensity, minimizing the effect of this initial bias.

Sample size. It was hoped to sample eight storms for each configuration. This choice balanced budgetary constraints against reliability of the resultant data set and ability to make statistically valid conclusions. However, numerous unforeseen problems were encountered, and the data set had to be reduced to six storms for each configuration to remain within budget.

Variability in Target Pollutant Concentration

It was mentioned above that one assumption of flow-proportional sampling is that the pollutant concentration is constant. In reality, it is difficult to know how the pollutant loading is distributed over the storm without intensive, incremental monitoring. Even then, it is unlikely that the distribution would be the same for each storm. Table E-1 compares data for two storm inflow samples from a January 10 storm. One sample is for the entire event, one is for the last hour only. For most constituents, the last hour showed lower pollutant concentrations than for the entire storm event. An exception was the nitrate-nitrite concentration, which was higher during the last hour. Dissolved metal concentrations were near the detection level in both samples. The runoff hydrograph is shown in Figure E-1. This event produced 0.25 inches of rain in 4.5 hours, with an average flow of 0.04 cfs.

One method used in this study to estimate the variability in pollutant concentration in stormwater samples was to include field replicas. Instead of filling just one sample container from the composite sample collected, two containers are filled for laboratory analysis.

Field replicas were done on the inflow sample for the January 23, 1992 storm. Results were generally within 20 to 25 percent relative percent difference (RPD). Exceptions were fecal coliforms, which showed a difference of 24 percent, which is very good agreement for fecal coliform tests, and two metals, copper and dissolved iron. Both these metals were near detection levels, and even though the numerical value of the RPD is large, has little practical significance. Data are given in Table E-2.

Table E-1. Comparison Of Different Sampling Periods, January 10 Storm Inflow Samples			
Parameter	Flow-Proportioned Entire Storm 92-A000431	Last Hour 92-A000429	Comments
$NO_2 + NO_3$	0.33 / 0.32	0.64	Higher
Ortho-P	< 0.005 *	< 0.005	Below DL
TP	0.13 / 0.15	0.024 *	Lower
BAP	< 0.018 *	< 0.018 *	Below DL
TSS	66 / 59	10	Lower
Turbidity	33 / 51	6.8	Lower
Total Metals			
Cu	0.012 / 0.008	0.004 *	Lower
Pb	0.007 / 0.011	0.017	Higher
Zn	0.042 / 0.065	0.034	Similar
Al	0.58 / 1.7	0.51	Similar
Fe	0.52 / 2.0	0.41	Similar
Dissolved Metals			
Cu	0.001 *	0.001 *	Same
Pb	0.001 *	0.001 *	Same
Zn	0.024	0.02	Same
Al	0.05 *	0.07	Same
Fe	0.02 *	0.04 *	Same
Fecal Coliform			
	162 / 275	81	Lower

Note: Values separated by a / for sample 92-A000431 are field duplicates

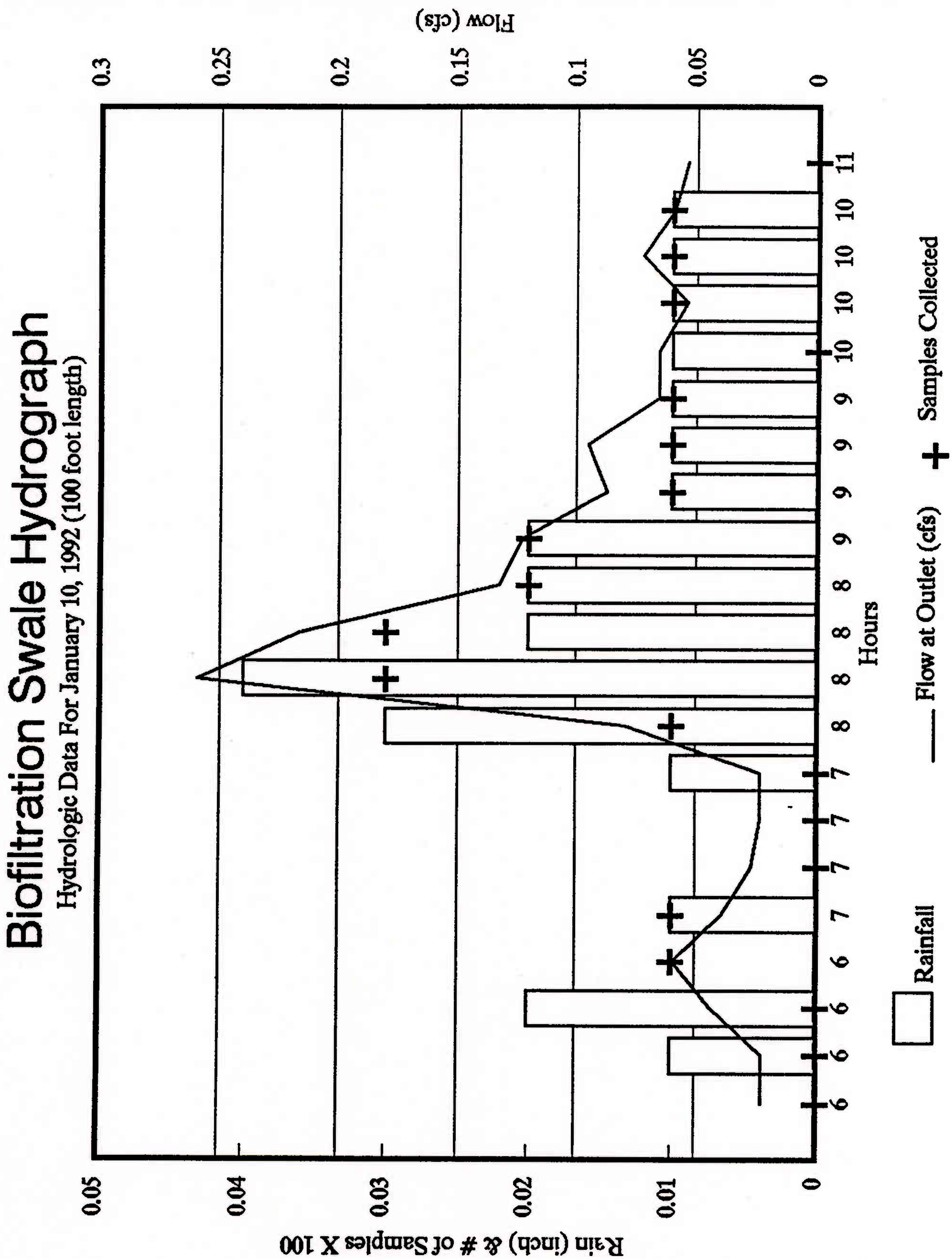

Figure E-1. Biofiltration Swale Hydrograph

Table E-2. Comparison Of Duplicate Storm Inflow Samples, January 23, 1992			
Parameter	Inflow 92-A001518 (mg/L)	Field Duplicate 92-A001520 (mg/L)	Relative Percent Difference (%)
$NO_2 + NO_3$	0.23	0.23	0
Ortho-P	< 0.005 *	< 0.005 *	—
TP	0.025 *	0.032	22
BAP	0.030	0.033	9
TSS	130	110	15
Turbidity	51	47	8
Total Metals			
Cu	0.006 *	0.004 *	40
Pb	0.044	0.017	4
Zn	0.096	0.034	2
Al	1.3	0.51	8
Fe	1.5	0.41	13
Dissolved Metals			
Cu	0.001 *	<0.001 *	—
Pb	0.001 *	<0.001 *	—
Zn	0.002 *	<0.002 *	—
Al	0.20	0.24	17
Fe	0.04 *	0.06	33
Fecal Coliform			
—	162	212	24

* < 5 time detection level

Contamination Concerns

To check for possible contamination being introduced into the sample from the collection equipment, "blanks" are commonly run. For this study, both field rinsate blanks and general field blanks were collected. A blank is prepared by using a source of water known to be free of contaminants, in this case, deionized distilled water (DDW), and running the typical laboratory analysis on the sample.

For the field rinsate blank, DDW was run through the ISCO sampler after normal field cleaning procedures had been carried out. Results are given in Table E-3. Only very low concentrations of a few pollutants were seen, except for dissolved zinc. Since zinc was below detection in the unfiltered sample, it appears likely that some zinc was contributed during filtration of the sample. This interpretation is also consistent with data for the stormwater samples, although the DDW blank failed to reveal trace zinc contamination.

Table E-3. Field Rinsate Blank Results (sample taken prior to March 27, 1992 storm)

Parameter	Rinsate Blank 92-A006543 (mg/L)
$NO_2 + NO_3$	0.035 *
Ortho-P	< 0.005 *
TP	< 0.005 *
BAP	< 0.005 *
TSS	1 *
Turbidity	0.6
Total Metals (mg/L)	
Cu	0.001 *
Pb	0.001 *
Zn	< 0.002 *
Al	0.05 *
Fe	0.02 *
Dissolved Metals (mg/L)	
Cu	<0.001 *
Pb	<0.001 *
Zn	0.042
Al	0.04 *
Fe	0.03 *

* < 5 time detection level

These results increase confidence that, except for zinc, pollutants seen in the samples were not artificially introduced from the collection equipment, but were actually present in the stormwater sampled. They also reveal that small amounts (0.02 ppm) of zinc contamination are introduced into the samples by filtration.

Field blanks were also filled with DDW. Containers were filled and labeled in the field, then treated identically to stormwater samples and submitted for laboratory analysis. These blanks serve to check for additional sources of potential contamination, such as from containers, sample transferring, as well as from the laboratory analysis process itself. Field blanks were run with the January 24 storm samples. No contaminants were seen except for trace levels of TSS and turbidity.

Accuracy of Analysis (Data Validation)

In addition to concerns about representation of the sample, variability in the stormwater itself, and possible extrinsic contamination sources, there is an additional set of concerns about the accuracy of the laboratory analysis. These will only be discussed briefly, since other documents thoroughly discuss this material (Bleyler, R., 1988, Ecology, 1988).

Holding times. Specific holding times and preservation techniques have been established for a number of laboratory analyses. The holding times specified in the 30 CFR 136, Federal Register, Volume 49 No. 209, Friday, October 1984 were used. Compliance with holding times was determined by comparing information provided by AMTest on the dates for sample digestion or analysis with the sample delivery date (sample delivery was the same day as sample collection, unless samples were either frozen or otherwise preserved, as discussed in the sampling plan).

No official holding time has been set for bio-available phosphorus, since the method is not standardized. The length of time exceeding the 48-hour ortho phosphorus holding time was noted. Variation was between 5 and 34 days, with the average being about 17 days. No pattern was noticed between holding times and a bias toward decreasing BAP concentrations.

A number of conventional parameters were seen to exceed holding times on occasion. These data were qualified using a J, meaning the value given is an estimate, or UJ meaning the value may be below the quantitation limit. The bias caused by this exceedance was considered in data analysis and discussion. Turbidity commonly exceeded the specified holding time of 48 hours. However, this was not considered a problem since little organic matter that could alter turbidity was typically present in the samples. No metals exceeded holding times.

Detection limits. Detection limits for each analysis were reported with all data. Most of the time, the detection limit reported was the same as the instrument detection limit. On occasion, the bio-available phosphorus detection limits were higher than the instrument detection level due to effects of sample preparation.

In general, reliable quantitation of a chemical is not possible at the detection level (DL). For most chemicals, a factor of three to five is applied to the detection level to obtain an accurately and reproducibly quantified number, which is referred to as the quantitation limit (EPA, 1989, page 5-8).

For the Biofiltration Project, the data validation sheets indicate whether the value reported is less than 5 times the DL. These data are indicated with an asterisk in Section 5, Tables 5-2, 5-3, and 5-4.

In determining percent removal performance, data quantitation limits were used as follows.

- If both inflow and outflow concentrations were below the DL, no percent removal value was reported.
- If inflow and outflow concentrations were less than 5 times the DL, and the outflow concentrations were below the DL, no percent removal was reported.
- If inflow concentrations were greater than 5 times DL and outflow concentrations were below or less than 5 times the DL, percent removals were reported with a > symbol preceding the calculated removal.
- If both inflow and outflow concentrations were greater that 5 times the DL, percent removals are given as the value calculated by the formula:

  (In - Out / In) * 100 = percent removal.

Matrix spike recovery. This procedure involves adding an analyte to a sample, then running the analysis to see if recovery of the material can be demonstrated. Spike recovery should be within 75 percent - 125 percent. For the Biofiltration Project, information on matrix spikes was received for fall and winter storm events. No problems were seen with spike recovery, which would be expected with stormwater samples, which have little matrix interference compared to such media as sediment or soil.

Split samples with other laboratories. Another indication of precision in sample analysis is to analyze the sample in two different laboratories using the same analytical methods. This was done for the July 24, 1991 storm event. The split sample was run both at AMTest, as usual, and at Metro Environmental Laboratories. Results from split samples run at different laboratories typically do not agree as closely as splits run at one laboratory. However, general concentration ranges and trends should be consistent. Table E-4 presents data from both labs.

Table E-4. Results of July 24, 1991 Sample from AMTest and Metro				
Parameter	AMTest		Metro	
	Inflow mg/L)	Outflow (mg/L)	Inflow mg/L)	Outflow (mg/L)
$NO_2 + NO_3$	0.47	1.2	0.86	1.4
Ortho-P	0.031	0.027	0.033	0.010
TP	0.34	0.24	0.206 / 0.416	0.259 / 0.253#
BAP	0.131	0.097	—	—
TSS	180	26	—	—
Turbidity	41	14	—	—
Total Metals (mg/L)				
Cu	0.013	0.009 *	0.030	0.01
Pb	0.05 *	< 0.02	0.087	0.01
Zn	0.21	0.073	0.28	0.066
Al	3.0	0.76	4.1	1.1
Fe	4.5	0.99	6.5	1.3
Dissolved Metals (mg/L)				
Cu	0.010	0.013	0.009	0.01
Pb	< 0.02 *	< 0.02 *	< 0.003 *	<0.003
Zn	0.11	0.55	0.78	0.048
Al	0.22	0.02	0.1	0.1
Fe	0.13	0.12	0.1	0.2
Fecal Coliform				
	150	431	1,300	2,200

* < 5 time detection level
# Laboratory duplicate values

Laboratory duplicate relative percent differences (RPD). Laboratory duplicates indicate only the precision of the laboratory method. The sample submitted to the lab is split after delivery to the lab, and both samples run through the analytical method. The RPD between the two samples should be within 20 percent. On occasion, problems were seen with RDP values being outside this range. Such data was qualified using a J descriptor, or UJ if near the detection level.

Other Laboratory administered quality control. In addition to the quality control information discussed above, the analytical laboratory used performs routine QAQC in keeping with requirements for laboratory accreditation. Some of these procedures include instrument calibration, use of method and instrument blanks, run duplicates, and interference checks.

Qualifiers used in validating data (after Bleyler, 1988)

J value is an estimate

UJ value may be below the limit of quantitation

R value is unusable

SAMPLING PLAN

Sampling goals were to collect samples for 6 storm events for both the 200- and 100-foot swale configurations. Flow proportional composite samples were to be collected by ISCO automatic samplers, triggered by a UNIDATA variable resistance depth gage and data logger. Discreet grab samples were to be taken for oil and grease analysis when storms occurred during normal working hours and if an oil sheen was visible. Samples were submitted to AMTEST Inc. in Redmond, Washington for analysis of contracted parameters.

Criteria for Storm Sample Collection

To the extent practical, storm events to be monitored were to follow a dry period of at least 48 hours from a previous storm that produced significant runoff (approximately 0.1 inches of rainfall). Ideal storms would yield between 0.10 to 1.5 inches of rainfall in an 8 hour period. Very large events (greater than a two year 24-hour storm) would not be sampled.

Field Procedures

In preparation for each sampling cycle the swale was inspected for normal wear and tear and vandalism. Repairs and/or maintenance were performed as necessary.

When all was found to be in working order, setup was as follows:

- Sediments and debris were removed from flumes.
- Sampling tubes were backflushed with 1 liter distilled water.
- Charged batteries and clean sample jars were placed in ISCO samplers.
- UNIDATA data logger and ISCO samplers were placed in active state (ready to collect sample(s) upon receiving pulse(s) from the data logger).
- Manual grab samples were collected for oil and grease analysis whenever reasonably convenient if a visible oil sheen could be observed during an event. It was assumed that if no sheen was visible, oil and grease levels would be below method detection

limits. Oil and grease samples were not collected on weekends or at night.

Field Log Book

A log book was maintained as a record of all information pertaining to sample collection, handling, and delivery, and sampling system maintenance. Types of information recorded included:

- Date and time samplers set
- Date and time samples retrieved
- Observations of oil sheen
- Date, time, and stage for oil and grease sample collection
- Splitting and delivery of samples to analytic laboratory
- Any special handling of samples (manual compositing, filtering, preservation, etc.)
- Notes pertaining to trouble-shooting and remedial procedures
- Any other notes thought to be of potential use

Sample Handling and Preservation

Flow-proportional composite samples were collected by ISCO samplers into 10 liter glass jars which had been cleaned as follows:

- A no-phosphorus detergent wash with nylon brush and hot tap water
- Hot tap water rinse (4 times)
- Acid rinse with 2 percent reagent grade sulfuric acid
- Distilled water rinse (6 times)

Following a sampling cycle, samples were retrieved from samplers and brought back to the City of Mountlake Terrace laboratory for splitting into sample bottles provided by the contracted analytical laboratory (AMTEST) as follows:

- 1 L polyethylene for physical parameters and filtering for ortho-phosphate and dissolved metals
- 1 L glass for oil and grease

- 500 ml polyethylene for metals
- 250 ml polyethylene for nutrients
- 250 ml polyethylene for fecal coliforms

Samples were identified by the date and time they were retrieved from samplers and by a "000", "100", or "200", to indicate the inlet, the outlet for the 100-foot configuration, or the outlet for the 200-foot configuration, respectively.

Samples were then packed in ice and delivered to AMTEST accompanied by a chain of custody form and an analysis request sheet, for analysis of the contracted parameters.

It was requested that AMTEST not supply preservatives in sample bottles since samples would be delivered within a few hours of retrieval to meet holding times for fecal coliforms and filtering for ortho-phosphate and dissolved metals. Samples were to be preserved as necessary by AMTEST upon delivery.

When the holding time for fecal coliforms could not be met, samples were filtered at the Mountlake Terrace laboratory for ortho-phosphate and dissolved metals and preserved as follows:

- Filtrate for ortho-phosphate and dissolved metals frozen
- Total nutrients preserved (0.1 percent sulfuric acid)
- Total metals preserved (0.1 percent nitric acid)
- Oil and grease preserved (0.5 percent sulfuric acid)

The samples could then be stored at 4°C, and delivered to AMTEST with samples from the next storm event.

APPENDIX F

MANNING'S n INVESTIGATION

- Memo from Gary Minton RE: Grass Blade Density
- Raw Data Tables

  Depth and Velocity Measurements/King County and City of Redmond Data from September 10, 1991 and October 21, 1991 Tests
- Distribution of Manning's n Values

APPENDIX F

MANNING'S n INVESTIGATION

MEMO FROM GARY MINTON RE: GRASS BLADE DENSITY

September 13, 1991

To: Phil Cohen

From: Gary Minton

Subject: Biofilter research project, tally of grass blade density in the Mountlake Terrace biofilter.

Here is the information I gathered. On Wednesday, September 11th I visited the site. Blade density information was gathered in three locations: about 10 feet up from the outlet flume, about 10 feet down from the rain gage, and about midpoint between the filter entrance and the rain gage. Call them Sites A, B, and C.

Material was gathered as follows at each location. A area of approximately 1 ft^2 was identified. A 1 ft^2 area was marked out with tent pegs and string. Grass within the sample site and immediately around it was first trimmed to a height of about 6" using hand shears. Grass within the sample site was then cut a second time and placed in a plastic bag. If the grass at the site was knocked down from the previous day's test, I first "stood" the grass up.

Upon return to the office, the grass at each site was weighted. After mixing the grass thoroughly, $^1/4$ of the sample by weight was removed and the number of blades were counted. Here is the tally as well as the info on blade width.

Site/Location	Density	Blade Width
A: 10' up from outlet flume	1,300/ft^2	About 25% were of a species with a typical width of 0.2" Rest narrow, 0.025" to 0.05"
B: midpoint 10' from rain gage	1,600/ft^2	Similar to the above station
C: about 50' from entrance	600/ft^2	About 50% of 0.2" width and 50% with width of 0.025" to 0.05"

The thickness of grass was noticeably less in the upper third of some of the filter. The surface of the grass gives the impression that the vast majority of grass is broad bladed. But down beneath the surface I notice that most of the grass is narrow in width, and deteriorated in appearance. Bare spots sometimes exist where the grass has died out.

I would like to return to count the blade density again once you have the filter operating at a lower grass height.

cc Louise Kulzer

Table F-1. King County SWM Velocity Meter—Depth and Velocity Field Data of September 10, 1991

TIME	HUB I.D. A1		B1		C1		D1		E1		F1	
	DEPTH	VELOC.	DEPTH	VELOC.	DEPTH	VELOC.	DEPTH	VELOC.	VELOC.	DEPTH	DEPTH	VELOC.
13:55	0.25	0.41	0.24	0.56	0.26	0.67	0.25	0.82	0.18	0.36	0.08	0.22
14.32	0.29	0.55	0.3	0.93	0.29	1.16 +_	0.29	1.20+_	0.23	0.68	0.15	0.3
	A2		B2		C2		D2		E2		F2	
	0.27	0.68	0.29	0.57	0.27	0.42	0.3	0.4	0.26	0.44	0.22	0.5
	0.32	0.74	0.32	0.62	0.33	0.63	0.33	0.59	0.3	0.43	0.17	0.48
	A3		B3		C3		D3		E3		F3	
12:55	0.26	0.34	0.29	0.42	0.34	0.95	0.29	0.34	0.26	0.38	0.19	0.35
	0.34	0.55	0.35	0.47	0.38	1.28+_	0.35	0.3	0.33	0.4	0.25	0.38
	A4		B4		C4		D4		E4		F4	
14:05	0.27	0.44	0.28	0.33	0.31	0.46	0.31	0.35	0.3	0.46	0.29	0.37
15:53	0.32	0.53	0.35	0.49	0.38	1.1	0.37	0.71	0.34	0.39	0.35	0.33
	A5		B5		C5		D5		E5		F5	
	0.21	0.39	0.3	0.44	0.25	0.36	0.25	0.58	0.29	0.53	0.3	0.44
	0.26	0.46	0.36	0.52	0.31	0.75	0.3	0.78	0.35	0.9	0.36	0.46
	A6		B6		C6		D6		E6		F6	
	0.17	0.49	0.2	0.44	0.25	0.45	0.22	0.44	0.24	0.83	0.28	0.54
	0.22	0.38	0.26	0.42	0.31	0.53	0.3	0.52	0.3	0.73	0.31	0.47

Notes:

1. Average Grass Height of 0.85 feet
2. Readings by John K. and Tim C. for A1, A2, A3, A4, A5, A6
3. Used KC Marsh McBirney Flow Meter Model 201D, calibrated at 9.86

Table F-2. Redmond Velocity Meter—Depth and Velocity Field Data of September 10, 1991

TIME	HUB I.D. A1		B1		C1		D1		E1		F1	
	DEPTH	VELOC.	DEPTH	VELOC.	DEPTH	VELOC.	DEPTH	VELOC.	VELOC.	DEPTH	DEPTH	VELOC.
14:17	0.24	0.20	0.25	0.25	0.26	0.65	0.15	0.28	0.18	0.18	0.08	*
	0.30	0.75	0.30	0.78	0.30	1.18	0.31	0.74	0.21	0.32	0.13	0.15
	A2		B2		C2		D2		E2		F2	
14:25	0.27	0.45	0.30	0.52	0.28	0.34	0.30	0.19	0.26	0.24	0.22	0.36
16:05	0.35	0.51	0.37	0.43	0.35	1.03	0.35	0.32	0.30	0.24	0.28	0.33
	A3		B3		C3		D3		E3		F3	
14:30	0.28	0.19	0.30	0.18	0.32	0.43	0.30	0.05	0.28	0.18	0.31	0.30
16:12	0.32	0.43	0.35	0.30	0.40	1.56	0.35	0.12	0.34	0.27	0.24	0.24
	A4		B4		C4		D4		E4		F4	
13:45	0.22	0.26	0.28	0.10	0.32	0.23	0.30	0.35	0.28	0.29	0.28	0.28
15:35	0.33	0 0.44	0.37	0.28	0.40	0.78	0.40	0.52	0.37	0.20	0.36	0.14
	A5		B5		C5		D5		E5		F5	
	0.22	0.24	0.30	0.24	0.26	0.23	0.25	0.35	0.29	0.41	0.29	0.29
15:40	0.31	0.37	0.37	0.35	0.35	0.70	0.31	0.56	0.35	0.56	0.37	0.30
	A6		B6		C6		D6		E6		F6	
13:58	0.18	0.20	0.20	0.15	0.24	0.24	0.22	0.20	0.23	0.55	0.27	0.36
15:45	0.22	0.38	0.26	0.30	0.31	0.38	0.29	0.40	0.31	0.65	0.32	0.34

Notes:

1. Average Grass Height of 0.85 feet
2. Readings by Del F. and Zahid K. of A1, A2, A3;
3. Used City of Redmond's Marsh McBirney Flow Meter, Model 2010, Calibrated at 9.84

Table F-3. King County SWM Velocity Meter—Depth and Velocity Field Data of October 21, 1991

HUB ID		Depth Measured	Velocity 201 Meter	HUB ID		Depth Measured	Velocity 201 Meter	HUB ID		Depth Measured	Velocity 201 Meter
A1	1	0.150	0.310	A1	2	0.19	0.42	A1	3	0.15	0.52
A2	1	0.160	0.360	A2	2	0.19	0.60	A2	3	0.25	0.92
A3	1	0.140	0.160	A3	2	0.19	0.16	A3	3	0.24	0.23
A4	1	0.120	0.150	A4	2	0.17	0.20	A4	3	0.23	0.42
A5	1	0.06	n/a	A5	2	0.13	0.23	A5	3	0.18	0.37
A6	1	0.02	n/a	A6	2	0.06	n/a	A6	3	0.13	0.39
B1	1	0.15	0.30	B1	2	0.20	0.35	B1	3	0.24	0.51
B2	1	0.16	0.36	B2	2	0.19	0.60	B2	3	0.25	0.92
B3	1	0.15	0.30	B3	2	0.20	0.35	B3	3	0.24	0.51
B4	1	0.13	0.27	B4	2	0.19	0.26	B4	3	0.24	0.33
B5	1	0.16	0.26	B5	2	0.23	0.31	B5	3	0.28	0.32
B6	1	0.08	n/a	B6	2	0.13	0.21	B6	3	0.17	0.33
C1	1	0.14	0.27	C1	2	0.19	0.28	C1	3	0.22	0.33
C2	1	0.15	0.23	C2	2	0.20	0.29	C2	3	0.24	0.33
C3	1	0.14	0.27	C3	2	0.19	0.28	C3	3	0.22	0.33
C4	1	0.14	0.22	C4	2	0.21	0.25	C4	3	0.25	0.33
C5	1	0.11	0.24	C5	2	0.18	0.28	C5	3	0.22	0.34
C6	1	0.14	0.26	C6	2	0.17	0.34	C6	3	0.22	0.47
D1	1	0.13	0.29	D1	2	0.19	0.37	D1	3	0.22	0.42
D2	1	0.17	0.23	D2	2	0.23	0.25	D2	3	0.27	0.24
D3	1	0.13	0.29	D3	2	0.19	0.37	D3	3	0.22	0.42
D4	1	0.15	0.28	D4	2	0.22	0.37	D4	3	0.27	0.40
D5	1	0.12	0.25	D5	2	0.16	0.36	D5	3	0.20	0.53
D6	1	0.10	0.21	D6	2	0.15	0.26	D6	3	0.20	0.33
E1	1	0.07	0.00	E1	2	0.13	0.27	E1	3	0.17	0.40
E2	1	0.16	0.37	E2	2	0.22	0.41	E2	3	0.24	0.40
E3	1	0.07	0.00	E3	2	0.13	0.27	E3	3	0.17	0.40
E4	1	0.12	0.37	E4	2	0.20	0.41	E4	3	0.26	0.44
E5	1	0.11	0.45	E5	2	0.20	0.53	E5	3	0.24	0.64
E6	1	0.10	0.28	E6	2	0.15	0.42	E6	3	0.22	0.67
F1	1	0	0	F1	0	0	n/a	F1	3	0.03	n/a
F2	1	0.07	n/a	F2	2	0.17	0.38	F2	3	0.20	0.36
F3	1	0.04	n/a	F3	2	0.14	0.25	F3	3	0.19	0.41
F4	1	0.13	0.22	F4	2	0.19	0.27	F4	3	0.25	0.26
F5	1	0.14	0.18	F5	2	0.20	0.24	F5	3	0.25	0.30
F6	1	0.15	0.49	F6	2	0.22	0.38	F6	3	0.24	0.53

Notes: Flow rate: 1=0.330cfs, 2=0.419 dfs, 3=0.508 cfs
n/a=depth too shallow for reading by velocity meter

Table F-4. Redmond Velocity Meter—Depth and Velocity Field Data of October 21, 1991

HUB ID		Depth Measured	Velocity 201 Meter	HUB ID		Depth Measured	Velocity 201 Meter	HUB ID		Depth Measured	Velocity 201 Meter
A1	1	0.14	0.21	A1	2	0.20	0.35	A1	3	0.22	0.35
A2	1	0.13	0.29	A2	2	0.19	0.46	A2	3	0.22	0.43
A3	1	0.12	0.09	A3	2	0.20	0.18	A3	3	0.25	0.21
A4	1	0.10	0.15	A4	2	0.16	0.20	A4	3	0.21	0.26
A5	1	0.00	0.15	A5	2	0.13	0.15	A5	3	0.18	0.25
A6	1	0.00	n/a	A6	2	0.08	n/a	A6	3	0.12	0.27
B1	1	0.14	0.18	B1	2	0.19	0.26	B1	3	0.22	0.34
B2	1	0.16	0.27	B2	2	0.21	0.37	B2	3	0.26	0.43
B3	1	0.15	0.19	B3	2	0.22	0.20	B3	3	0.27	0.17
B4	1	0.12	0.14	B4	2	0.20	0.20	B4	3	0.23	0.24
B5	1	0.15	0.18	B5	2	0.22	0.24	B5	3	0.25	0.26
B6	1	0.10	n/a	B6	2	0.13	0.13	B6	3	0.18	0.21
C1	1	0.12	0.16	C1	2	0,18	0.23	C1	3	0.22	0.33
C2	1	0.15	0.18	C2	2	0.21	0.24	C2	3	0.25	0.18
C3	1	0.19	0.19	C3	2	0.25	0.23	C3	3	0.13	0.27
C4	1	0.12	0.13	C4	2	0.21	0.20	C4	3	0.25	0.21
C5	1	0.11	0.19	C5	2	0.19	0.21	C5	3	0.22	0.22
C6	1	0.13	0.19	C6	2	0.20	0.34	C6	3	0.22	0.38
D1	1	0.12	0.15	D1	2	0.17	0.27	D1	3	0.21	0.33
D2	1	0.18	0.13	D2	2	0.22	0.17	D2	3	0.22	0.27
D3	1	0.17	0.15	D3	2	0.22	0.26	D3	3	0.29	0.24
D4	1	0.12	0.22	D4	2	0.22	0.32	D4	3	0.26	0.37
D5	1	0.11	0.20	D5	2	0.16	0.30	D5	3	0.20	0.31
D6	1	0.13	0.13	D6	2	0.15	0.17	D6	3	0.20	0.28
E1	1	<0.1	<0.1	E1	2	0.12	0.24	E1	3	0.16	0.33
E2	1	0.11	0.13	E2	2	0.21	0.37	E2	3	0.25	0.33
E3	1	0.13	0.13	E3	2	0.21	0.24	E3	3	0.25	0.26
E4	1	0.12	0.12	E4	2	0.20	0.30	E4	3	0.24	0.34
E5	1	0.13	0.13	E5	2	0.20	0.49	E5	3	0.23	0.60
E6	1	0.13	0.13	E6	2	0.17	0.34	E6	3	0.21	0.50
F1	1	<0.1	n/a	F1	0	0.00	*	F1	3	<0.1	n/a
F2	1	0.11	0.26	F2	2	0.16	0.35	F2	3	0.21	0.45
F3	1	<0.1	n/a	F3	2	0.13	0.19	F3	3	0.14	0.24
F4	1	0.12	0.22	F4	2	0.20	0.22	F4	3	0.23	0.17
F5	1	0.12	0.14	F5	2	0.20	0.22	F5	3	0.22	0.27
F6	1	0.15	0.27	F6	2	0.19	0.26	F6	3	0.21	0.35

Notes: Flow rate: 1=0.330cfs, 2=0.419 cfs, 3=0.508 cfs

n/a=depth too shallow for reading by velocity meter

Table F-5. Velocity Meter Calibration Data

METER I.D. & TRIAL NO.	(FEET) DEPTH	Corr.Vel.	READ VEL. dig.	%IError	%CError	(FT/SEC.) VEL. meas.	VEL. dif.	FEET DIST.	SEC. TIME	Est. Corr.
K3	0.07	0.29	0.12	60%	2%	0.30	0.18	3	10	0.17
K1	0.08	0.20	0.06	70%	1%	0.20	0.14	3	15	0.14
K2	0.14	0.11	0.05	52%	7%	0.10	0.05	3	29	0.06
K5	0.16	0.17	0.12	32%	3%	0.18	0.06	3	17	0.05
K9A	0.16	0.23	0.18	4%	22%	0.19	0.01	3	16	0.05
K9	0.17	0.19	0.15	20%	4%	0.19	0.04	3	16	0.04
K10	0.20	0.28	0.24	13%	0%	0.28	0.04	8	29	0.04
K10A	0.21	0.27	0.24	7%	6%	0.26	0.02	8	31	0.03
K11	0.23	0.56	0.53	1%	5%	0.53	0.00	8	15	0.03
K7	0.23	0.17	0.14	11%	7%	0.16	0.02	3	19	0.03
K7A	0.25	0.15	0.13	13%	3%	0.15	0.02	3	20	0.02
K11A	0.25	0.51	0.49	8%	3%	0.53	0.04	8	15	0.02
K6	0.35	0.11	0.10	13%	0%	0.12	0.02	3	26	0.01
K8	0.41	0.11	0.10	7%	4%	0.11	0.01	3	28	0.01
K8A	0.43	0.10	0.09	24%	14%	0.12	0.03	3	25.5	0.01
C3	0.07	0.29	0.18	40%	2%	0.30	0.12	3	10	0.11
C1	0.08	0.20	0.09	55%	1%	0.20	0.11	3	15	0.11
C4	0.12	0.20	0.12	40%	2%	0.20	0.08	3	15	0.08
C2	0.14	0.12	0.05	52%	20%	0.10	0.05	3	29	0.07
C5	0.16	0.16	0.09	40%	4%	0.15	0.06	3	20	0.07
C5A	0.17	0.16	0.10	40%	3%	0.17	0.07	3	18	0.06
C10	0.19	0.31	0.25	13%	7%	0.29	0.04	8	28	0.06
C9	0.19	0.18	0.12	32%	0%	0.18	0.06	3	17	0.06
C10A	0.20	0.23	0.22	4%	0%	0.23	0.01	8	27	0.05
C9A	0.20	0.17	0.12	32%	2%	0.18	0.06	3	17	0.05
C11A	0.25	0.51	0.47	6%	2%	0.50	0.03	8	16	0.04
C11	0.25	0.52	0.48	10%	3%	0.53	0.05	8	15	0.04
C7	0.26	0.16	0.12	28%	6%	0.17	0.05	3	18	0.04
C7A	0.27	0.15	0.11	27%	3%	0.15	0.04	3	20	0.04
C6	0.32	0.11	0.09	25%	4%	0.12	0.03	3	25	0.02
C8	0.36	0.13	0.11	8%	7%	0.12	0.01	3	25	0.02
C8A	0.39	0.11	0.10	13%	2%	0.12	0.02	3	26	0.01

NOTES:

Velocity meters are Model 201manufactured by Marsh McBirney of Frederick, MD
Data from Univ. of Washington Hydraulics Laboratory, Seattle, WA (1/28/92)
Blue dye used for the "VEL. meas." determination
C = City of Redmond   K = King County SWM
% I.Error = %Instrument Error = 100%*(abs|VEL. dig. - VEL. meas.|/VEL. meas.)
%C.Error = % Corrected Error = 100%(abs|Corr. Vel. - VEL.meas.|/VEL.meas.)
King Co. meter correction formula: Corr. Vel. = VEL. dig. + Est. Corr. where Est. Corr. = 0.003(DEPTH)^-1.529
City of Redmond meter correction formula: Corr. Vel. = VEL. dig. - Est. Corr. where where Est. Corr. = 0.003(DEPTH)^-1.529
Correction formula from Alan Johnson of Aquatic Resource Consultants, Seattle, WA

Table F-6. Dye Velocity Tests for September 10 and October 21, 1991

SEPTEMBER 21, 1991 DYE VELOCITY TESTS

Sta.	Trial 1 Start @ 13:45 350 GPM E/T	Veloc. ft/sec	Trial 2 Start @ 14:15 50 GPM E/T	Veloc. ft/sec	Mean Veloc. Trials 1 & 2	Trial 3 Start @ 15:00 620 GPM	Vel. ft/sec	Trial 4 Start @ 15:15 620 GPM	Vel. ft/sec	Trial 5 Start @ 15:25 620 GPM	Veloc. ft/sec	Mean Veloc. Trials 3, 4 & 5
0+00	00:00	0.00	00:00	0.00	0.00	00:00	0.00	00:00	0.00	00:00	0.00	0.00
0+25	00:20	1.25	00:21	1.19	1.22	00:10	2.50	00:10	2.50	00:10	2.50	2.50
0+50	00:46	0.96	00:42	1.19	1.08	00:19	2.78	00:20	2.50	00:19	2.78	2.69
0+75	01:58	0.35	01:55	0.34	0.34	00:28	2.78	00:27	3.57	00:27	3.13	3.16
1+00	02:50	0.48	02:44	0.51	0.50	00:36	3.13	00:35	3.13	00:36	2.78	3.01
1+25	03:56	0.38	03:55	0.35	0.37	01:03	0.93	00:54	1.32	00:50	1.79	1.34
1+50	04:34	0.66	04:36	0.61	0.63	01:31	0.89	01:05	2.27	01:01	2.27	1.81

OCTOBER 21, 1991 DYE VELOCITY TESTS

Sta.	Trial 6 Start @ 13:45 200 GPM	Veloc. ft/sec	Trial 7 Start @ 14:15 200 GPM	Reach Veloc. ft/sec	Mean Veloc. Trials 6,7	Trial 8 350 GPM	Veloc. ft/sec	Trial 8 350 GPM	Veloc. ft/sec	Mean Veloc. Trials 7,8
0+00	00:00	0.00	00:00	0.00	0.00	***	***	***	***	***
0+25	00:00	0.00	00:00	0.00	0.00	00:00	0.00	00:00	0.00	0.00
0+50	01:10	0.36	01:10	0.36	0.36	00:43	0.58	00:43	0.58	0.58
0+75	02:35	0.29	02:40	0.28	0.29	01:28	0.56	01:26	0.58	0.57
1+00	04:03	0.28	04:10	0.28	0.28	02:17	0.51	02:16	0.50	0.51
1+25	06:40	0.16	06:30	0.18	0.17	03:10	0.47	03:13	0.44	0.46
1+50	08:00	0.31	07:50	0.31	0.31	03:55	0.56	03:57	0.57	0.56
1+68	09:10	0.26	09:00	0.26	0.26	04:34	0.46	04:37	0.45	0.46

Sta.		Sta.	LOCAL LANDMARK
0+00	VISQUEEN	1+00	4TH ROW, D-V MEAS. HUBS
0+25	UPSTREAM CONTROL STAKES	1+25	SWALE
0+50	DOWNSTREAM CONTROL STAKES	1+50	
0+75	MID-POINT	1+68	WEIR ENTR.

Notes: September 10, 1991 tests performed by P. COHEN, B. FRANKLIN, G. MINTON, R. HORNER—October 21 tests performed by P. COHEN and L. KULZER

Table F-7. Distribution Frequency of Manning's n Values

0.08	3	4%	0.17	18	25%
0.11	5	11%	0.20	16	48%
0.14	13	30%	0.14	13	66%
0.17	18	55%	0.23	9	79%
0.20	16	77%	0.11	5	86%
0.23	9	90%	0.26	5	93%
0.26	5	97%	0.08	3	97%
0.29	2	100%	0.29	2	100%

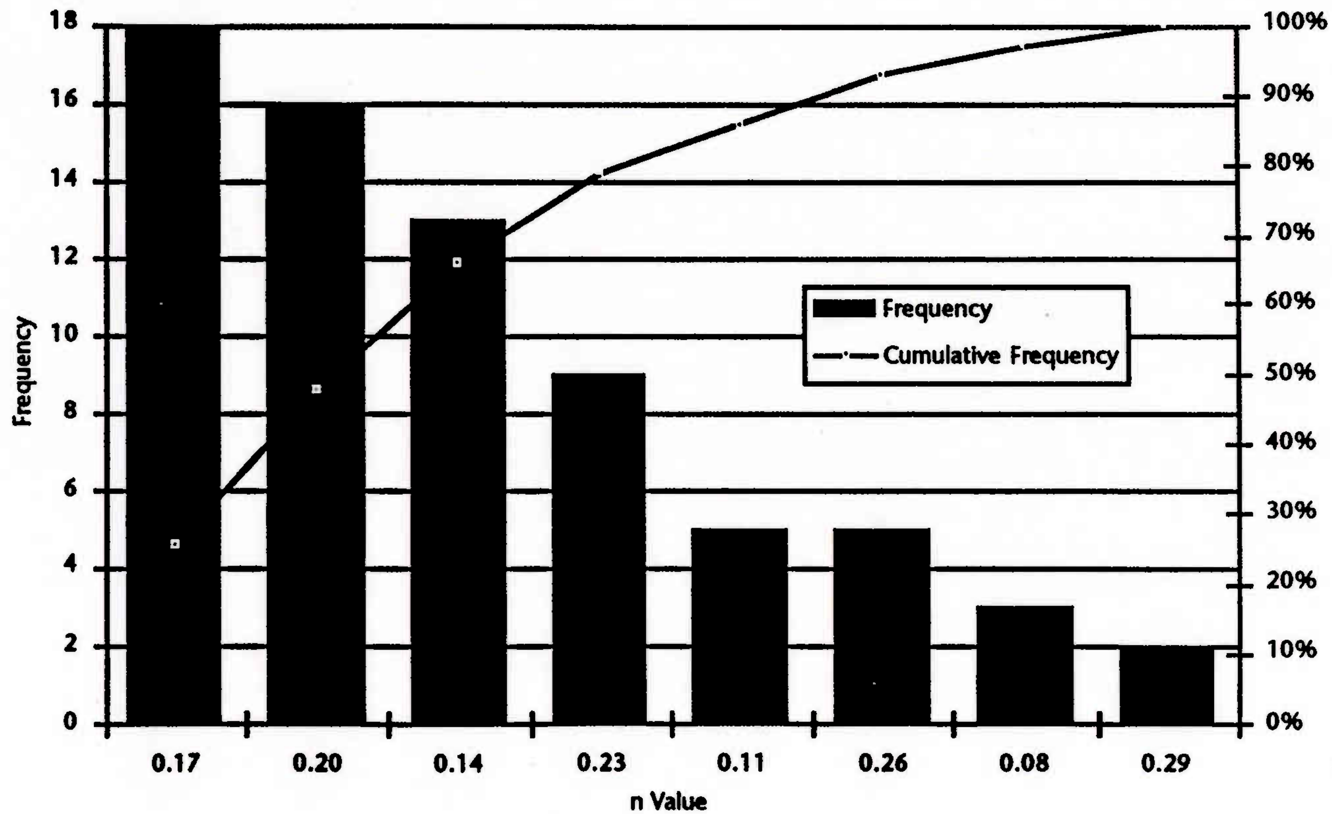

Figure F-1. Analysis of King County SWM Velocity and Depth Data Collected October 21, 1991